Exclusive Central Hadron Production in $p\bar{p}$ Collisions at the Tevatron for $\sqrt{s}$ = 1960GeV, 900GeV

Partial Wave Analysis - Full Status

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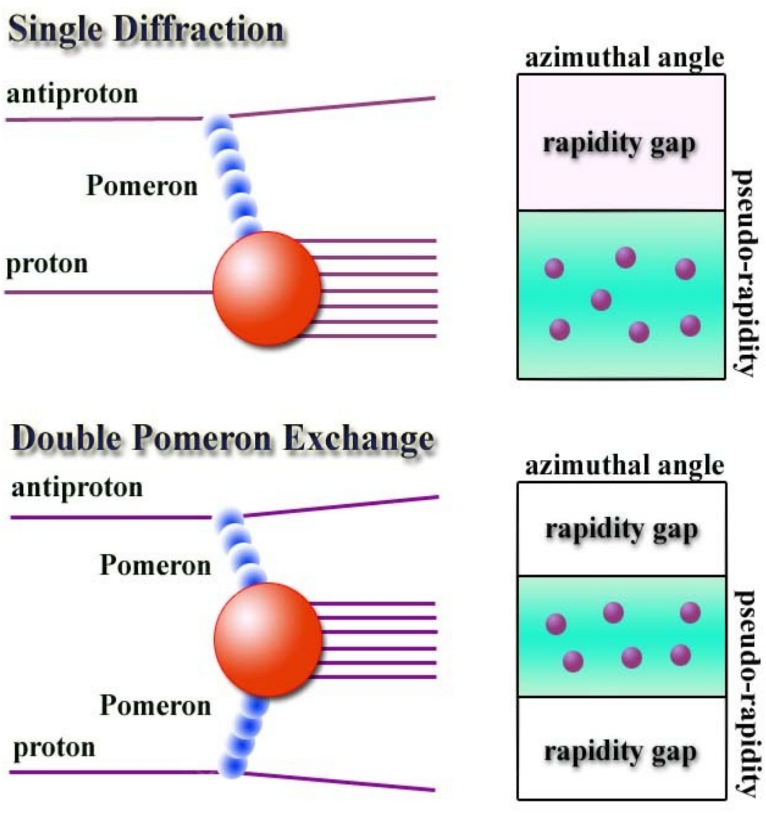
Contents

Physics Motivation
Double Pomeron Exchange

Pomeron:

- Carrier of 4-momentum between protons
- Strongly interacting color singlet combination of quarks or/and gluons
- Quantum numbers of vacuum
- LO: P = *gg*



Analysis

GXG reaction

$$\boxed{\bar{p} + p \rightarrow \bar{p} + \mathrm{GAP} + X + \mathrm{GAP} + p}$$

X (in this study)**:**

- hadron pair mostly $\pi^+ \pi^-$
- central $y \approx 0$
- between rapidity gaps $\Delta y \approx 4$
- $Q = S = 0$, $C = +1$, $J = 0$ or 2, $I=0$

Expected to be dominated by DPE in the t-channel!

Low Mass Central Hadronic State Analysis

Candidates selection

Trigger requirement:

- 2 central ($|\eta|<1.3$) towers with Et > 0.5 GeV
- PCAL ($2.11<|\eta|<3.64$) in veto
- CLC ($3.75<|\eta|<4.75$) in veto
- BSC1 ($5.4<|\eta|<5.9$) in veto

Gap cuts:

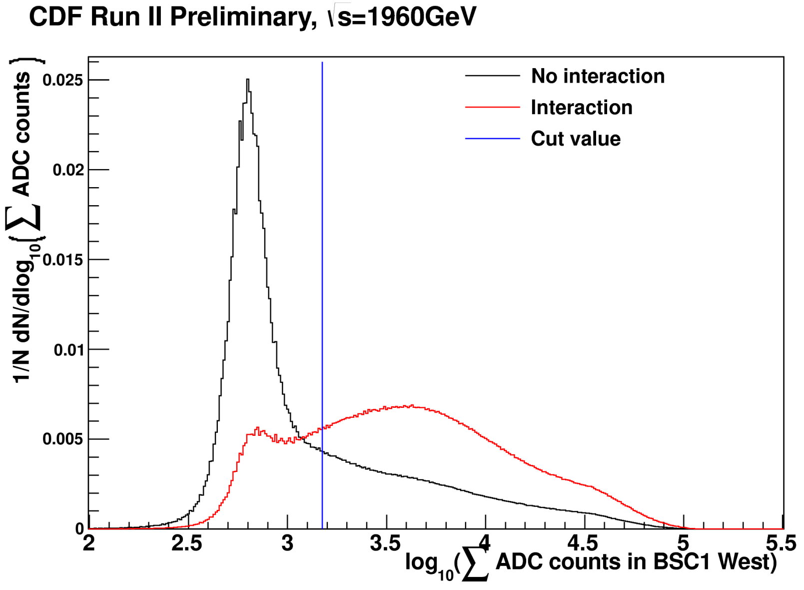
To determine noise levels in subdetectors we divide zero-bias sample from same periods into two sub-samples:

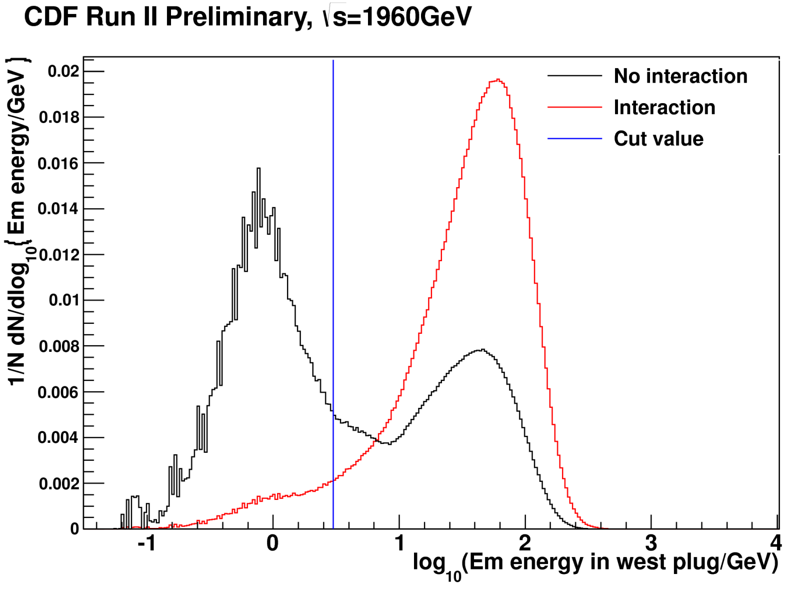
No Interaction:	**Interaction:**
•No tracks and •No CLC hits and •No muon stubs	At least one • Track or • CLC hit or • Muon stub

Low Mass Central Hadronic State Analysis

Candidates selection

Examples of exclusive requirements – empty forward detectors





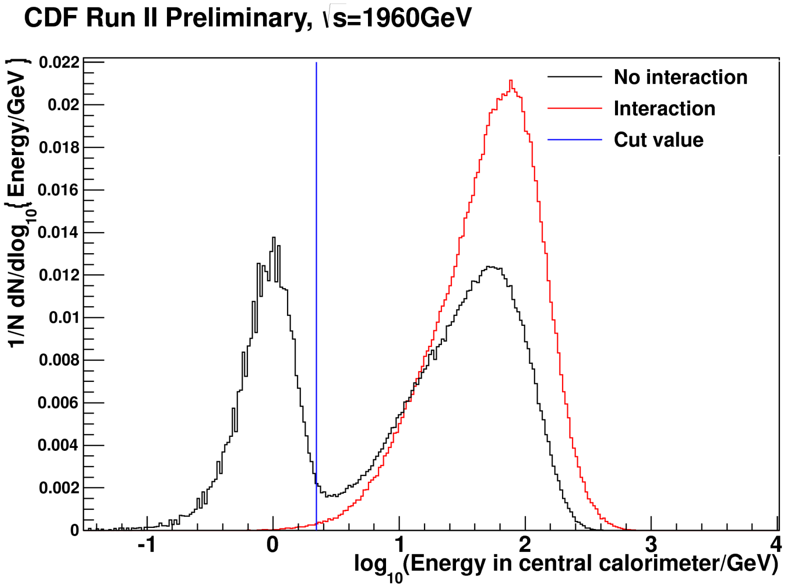
Low Mass Central Hadronic State Analysis

Candidates selection

Exclusivity cuts

To determine exclusive 2-4 tracks we apply similar technique in central region, just excluding cones of R=0.3 around each track extrapolation.

$$R=\sqrt{(\Delta\eta)^2+(\Delta\phi)^2}$$

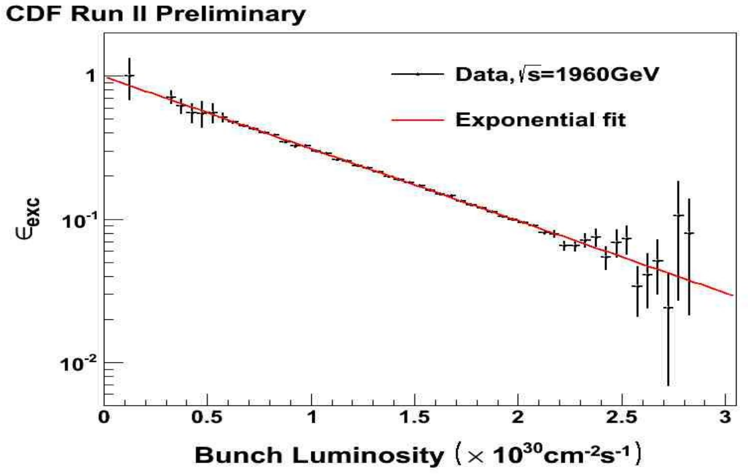


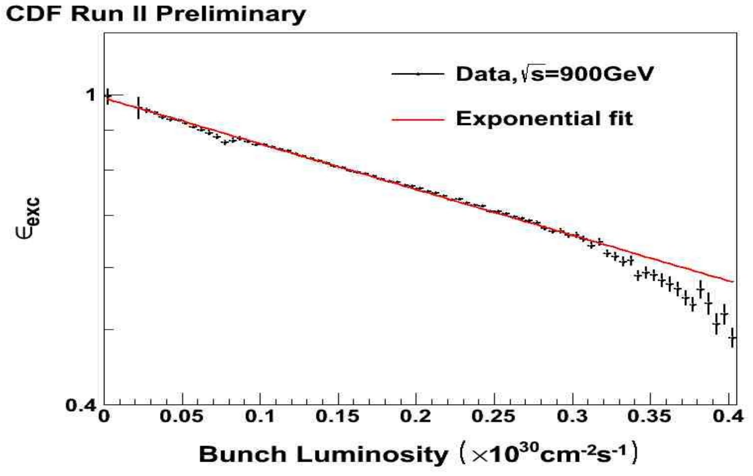
Effective exclusive luminosity

- Determination of efficiency of having no-pileup using zero-bias sample.

  We measure ratio of empty events (all detectors on noise level) to all events.

- Exponential drop with bunch luminosity.
- Slope corresponds to total detected inelastic cross section.





1960 GeV	900 GeV
53.88(36) mb	62.76(38) mb
1.18/pb	0.059/pb

Low Mass Central Hadronic State Analysis

Candidates selection

Additional cuts:

- quality of tracks

ΔZ_0, N of COT hits, χ^2/N_{dof}, p_T

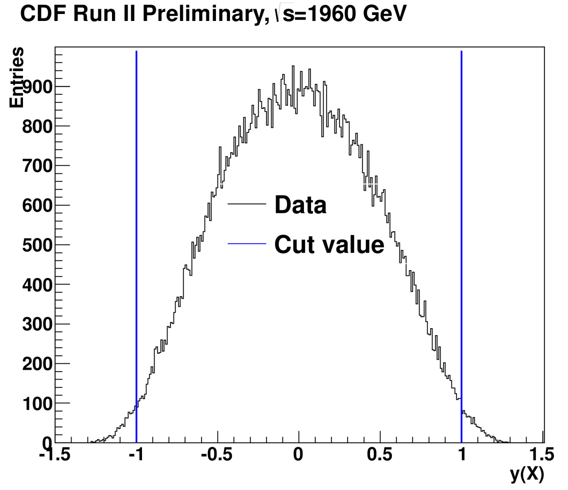
- cosmic ray rejection:

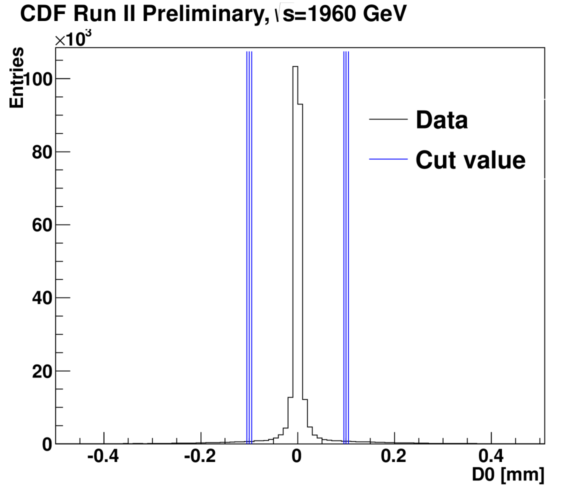
no muons, 3D opening angle, d_0

- Physical cuts:

η, rapidity of central state, total charge

Examples:
d_0, y(X)





Cut	1960GeV	900GeV
Triggered	92130 x 10^3	21737 x 10^3
Forward cleanup	59276 x 10^3	18749 x 10^3
2 tracks	4700 x 10^3	271 x 10^3
Quality + cosmic rejection + exclusivity	415413	8400
Opposite sign	350009	7595
Luminosity	7.12/pb	0.074/pb
Exclusive luminosity	1.18/pb	0.059/pb

Acceptance calculation

Model independent analysis

Kinematics cuts:

- $P_t(\pi)>0.4$ GeV/c
- $|\eta(\pi)|<1.3$
- $|y(\pi)|<1.0$

3 components:

- Trigger efficiency
- Single track acceptance
- 2 tracks acceptance

Trigger efficiency

1. Sample of min-bias data, good quality isolated (no other tracks in cone with R=0.4) tracks.

2. Checking how often they fired 0, 1, 2 or more trigger towers (>= 4 bits) in 3x3 box around track extrapolation.

3. Trigger efficiency composed from those 3 probability distributions (which are functions of P_t and η)

Before: trigger efficiency only in the function of P_t

Trigger efficiency

Probability of triggering 2 or more towers in the central detector by two independent tracks „a” and „b”:

$$\varepsilon = P_2(a)+P_1(a)*[P_1(b)+P_2(b)]+P_0(a)*P_2(b)$$

P_0 – probability of triggering no towers

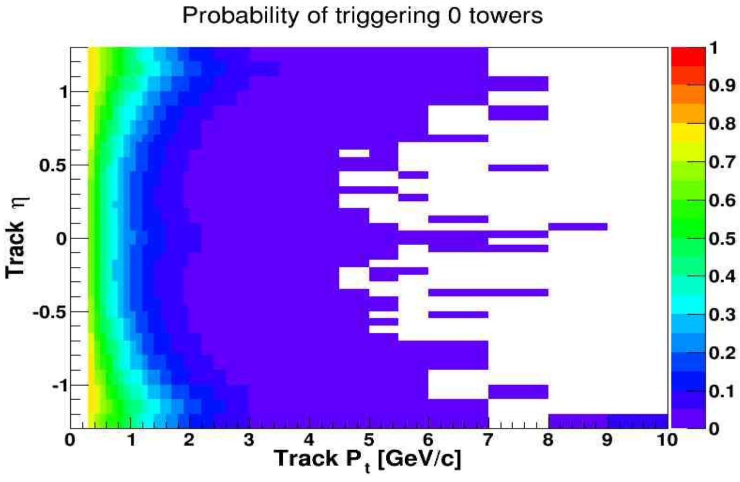
P_1 – probability of triggering one tower

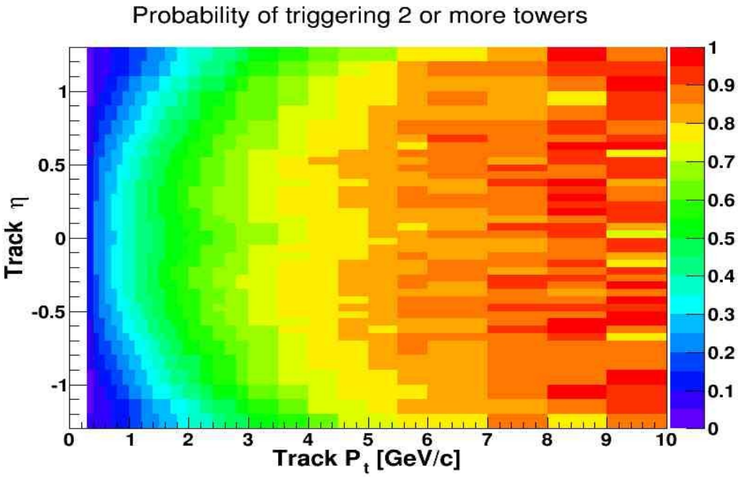
P_2 – probability of triggering two or more towers

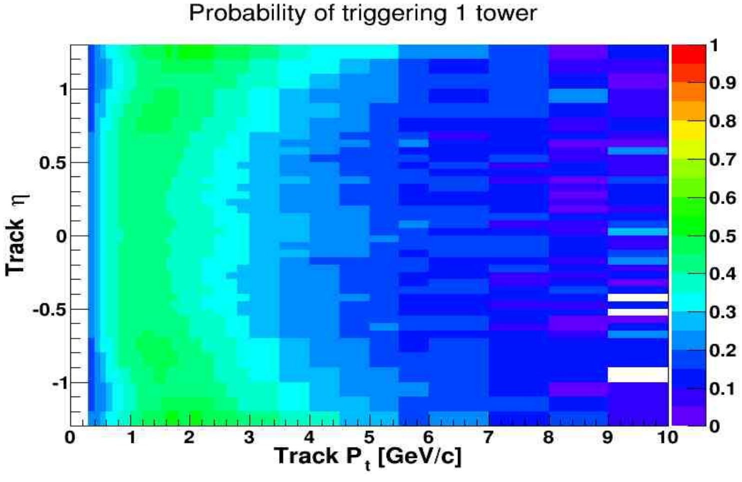
Trigger efficiency

	$P_2(b)$	$P_1(b)$	$P_0(b)$
$P_2(a)$	X	X	X
$P_1(a)$	X	X	
$P_0(a)$	X		

Trigger efficiency





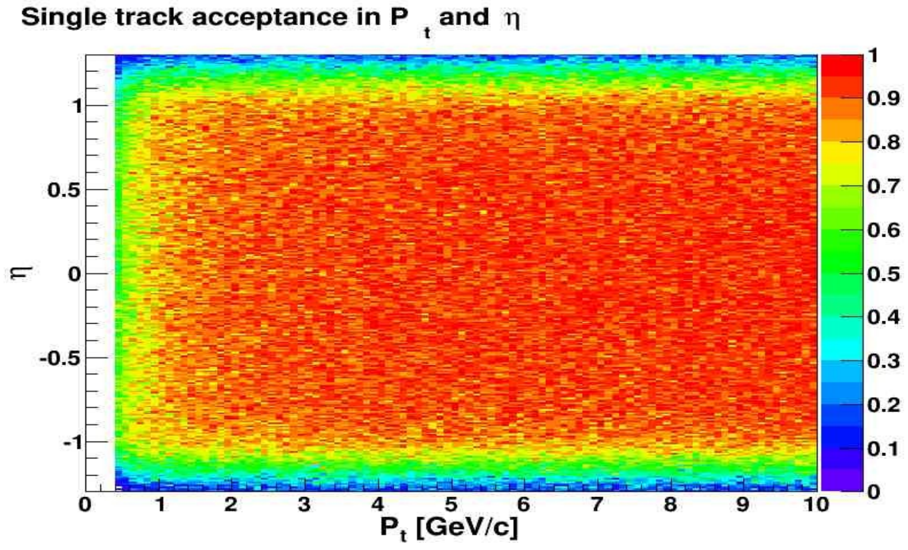


Single track acceptance

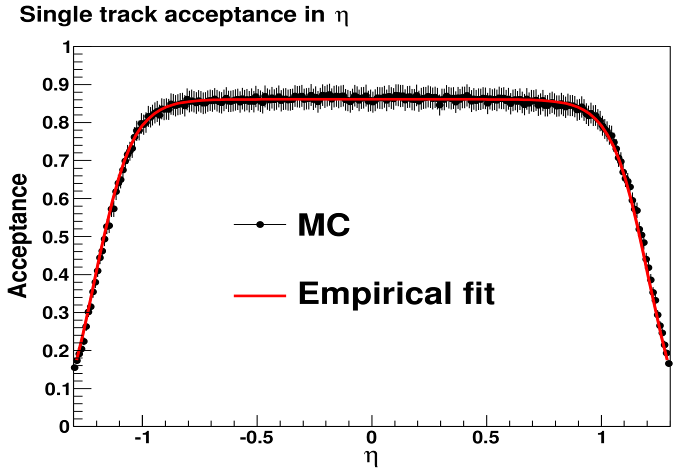
1. Single pion generation, flat in phi

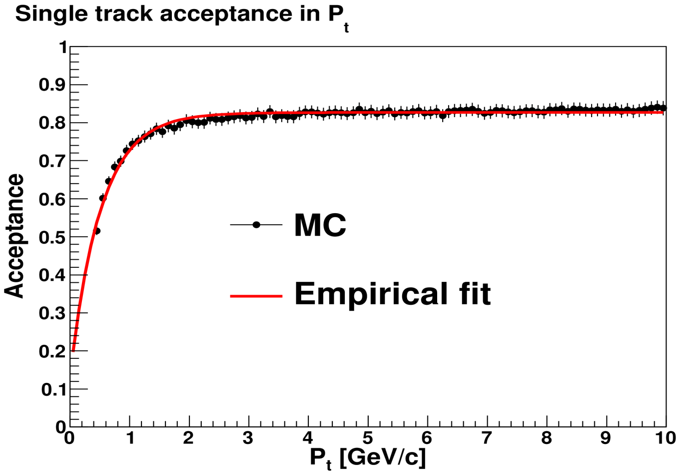
2. Acceptance in the function of Pt(track) and eta

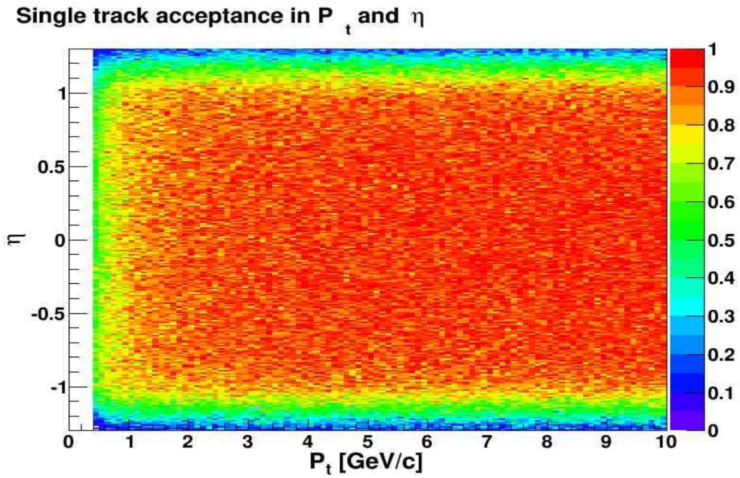
- Probability that track will be reconstruced at all
- Probability that track will pass all single track quality cuts

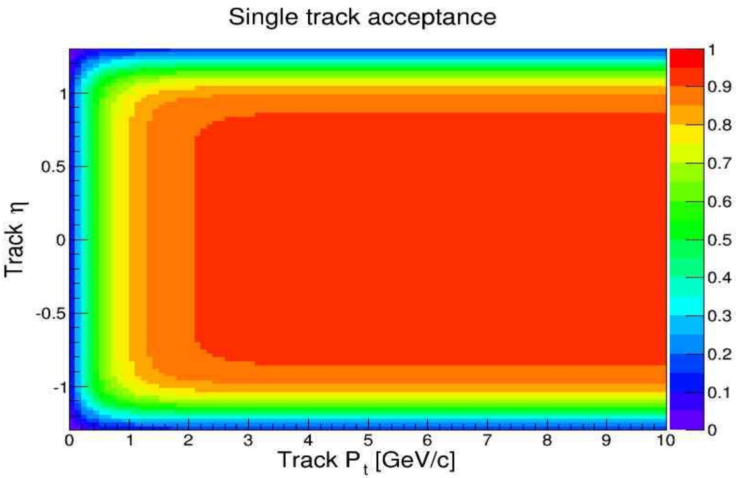


Single track acceptance









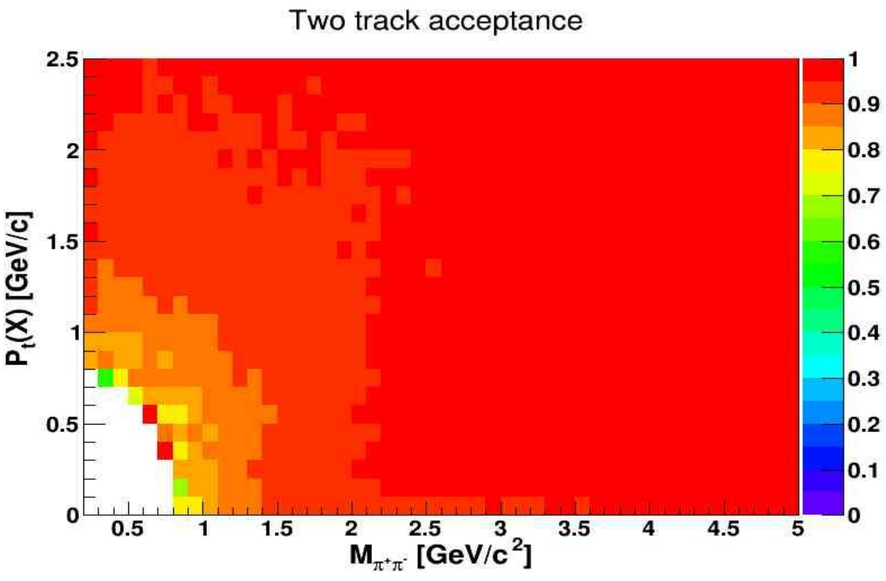
2 tracks cuts acceptance

Cuts:

- 3D opening angle
- y of central state
- Separation
- dZ0

Based on J=0 phase space model

All previous cuts applied before



Systematical uncertainties

1. All cut parameters varied by

   ~ 1 standard deviation (gaussian-like) or

   ~ 0.5 of FWHM width (Lorentz like)

   what looks resonably (others)

2. Trigger efficiency – statistical uncertainties of probability distributions

3. Same value of cut for E-W forward detectors.

4. Assumed independence of such systematics.

5. Applied simultanously in data/MC

Pt distribution for different mass ranges

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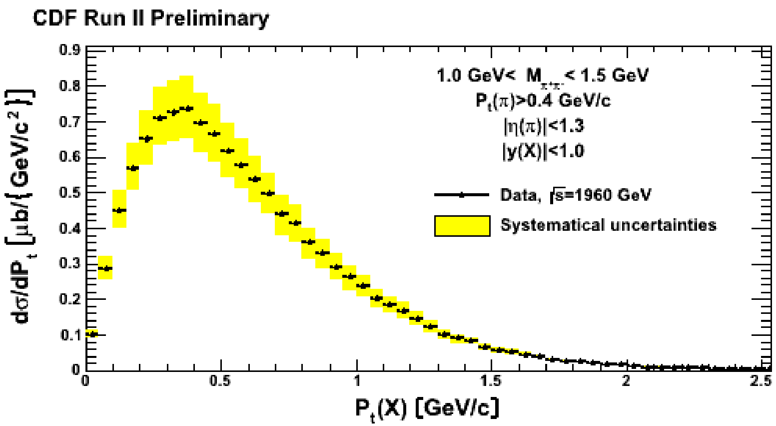

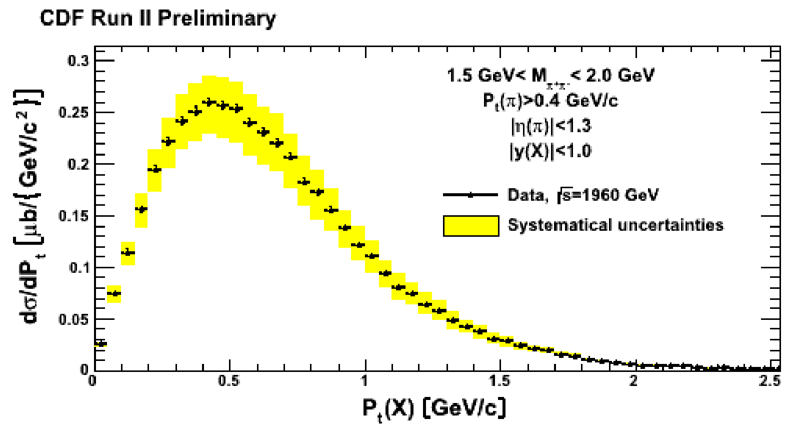

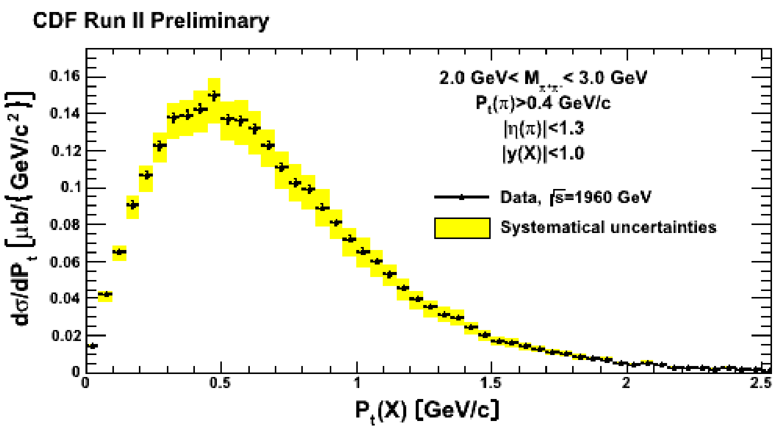

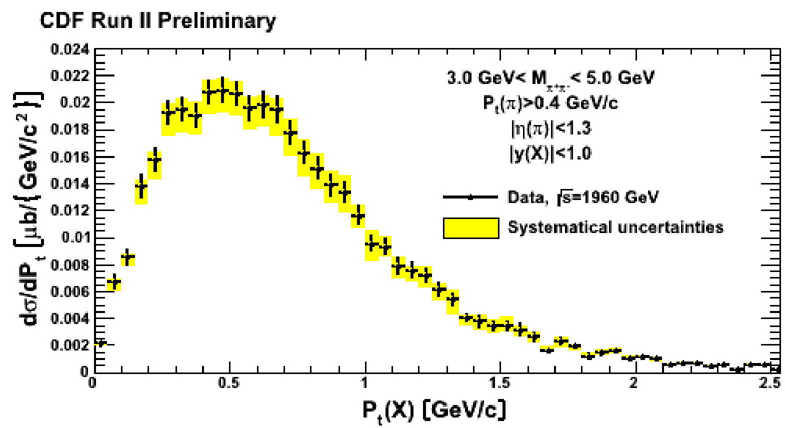

Mass distribution – tail fit

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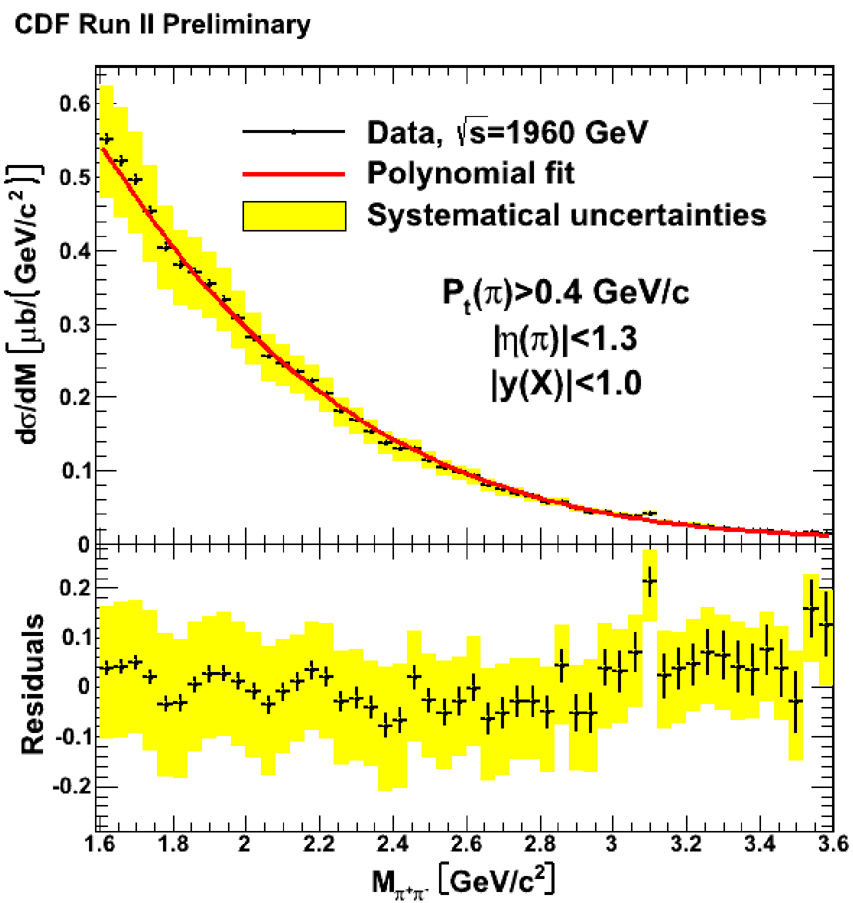


Question 1

Do we want to present all our spectra from $0.28 GeV/c^2$ in mass or from $0.8 GeV/c^2$?

Partial Waves Analysis - Idea

Unpolarized coss-section

$$\frac{d\sigma}{d\Omega} = \frac{1}{(2s_a+1)(2s_b+1)p^2} \sum_{(\lambda),J,J'} \left(J+\frac{1}{2}\right)\left(J'+\frac{1}{2}\right)(-1)^{\lambda-\mu}$$
$$\cdot \langle\lambda_a\lambda_b|\, T_J(E)\, |\lambda_c\lambda_d\rangle * \langle\lambda_a\lambda_b|\, T_{J'}(E)\, |\lambda_c\lambda_d\rangle$$
$$\cdot \sum_l C(JJ'l;\lambda,-\lambda)C(JJ'l;\mu,-\mu)P_l(\cos\theta)$$

M.Jacob, G.C.Wick, On the general theory of collisions for particles with spin, Ann. Phys. **7**, (1959) 404-428.

$$a+b\to c+d$$

- s_a, s_b - spins
- J, J' - total angular momenta
- $\lambda_a,\ \lambda_b,\ \lambda_c,\ \lambda_d$ - helicities; $\mu=\lambda_c-\lambda_d,\ \lambda=\lambda_a-\lambda_b$
- p - momentum of initial state particle, E - c.m. energy
- $T=i(1-S)$, S - scaterring matrix
- $C(JJ'l;\lambda,-\lambda)$ - C-G coefficients

Double Pomeron Exchange

Goal: $\langle \lambda_a \lambda_b | \, T_J(E) \, | \lambda_c \lambda_d \rangle = ?$

D$\mathbb{P}$E properties:

- $\pi^+\pi^-$ production only via s-channel diagrams
- $0^{++}, 2^{++}, 4^{++}, \cdots$ intermediate states only
  $\rightarrow$ each such state has a definite J
  $\rightarrow$ 0^{++} states contribute only to T_0
- $s_\pi = 0$, $s_{\mathbb{P}} = 0$, λ_π, $\lambda_{\mathbb{P}} = 0$
- Therefore: $\langle \lambda_a \lambda_b | \, T_J(E) \, | \lambda_c \lambda_d \rangle$ is a single complex number $\mathbf{R_J(E)e^{i\phi_J(E)}}$

Tool: Measurement of coefficients of Legendre polynomials a_l

0^{++} and 2^{++} central state assumption

- $J,\ J' = 0{,}2 \to l = 0{,}2{,}4.$
- Only non-zero C-G coefficients: $C(000;00)$, $C(022;00)$, $C(220;00)$, $C(222;00)$, $C(224;00)$

1. $l = 4 \to$ only $J = J' = 2$:
   $a_4 = \left(\frac{9}{7}\right)^2 p^{-2} R_2^2$
2. $l = 0 \to J = J' = 2$ or $J = J' = 0$:
   $a_0 = \frac{1}{4} p^{-2} \left(R_0^2 + R_2^2\right)$
3. $l = 2 \to J = J' = 2$ or $J = 0\,, J' = 2$ or $J = 2\,, J' = 0$:
   $a_2 = p^{-2}\left(\frac{5}{2} R_0 R_2 \cos(\phi_2 - \phi_0) + \left(\frac{5}{7}\right)^2 R_2^2\right),$
   where: $\delta = \phi_2 - \phi_0$ - relative phase

Finally:

1. $R_2^2 = p^2 \left(\frac{7}{9}\right)^2 a_4$
2. $R_0^2 = p^2 \left(4a_0 - \left(\frac{7}{9}\right)^2 a_4\right)$
3. $\delta = \frac{1}{2} \frac{a_2 - \left(\frac{5}{9}\right)^2 a_4}{\sqrt{\left(\frac{7}{9}\right)^2 a_4 \left(4a_0 - \left(\frac{7}{9}\right)^2 a_4\right)}}$

Legendre moments - correction for acceptance

Corrected Legendre moments **b** (vector):

$$\mathbf{b} = \mathbf{K}^{-1}\mathbf{a}\,.$$

a - not corrected Legendre moments, **K** following matrix:

$$K_{ll'} = \frac{\sum_i w_i P_l(\cos\theta_i) P_{l'}(\cos\theta_i)}{\sum_i w_i}\,,$$

where: $w_i = w_i^{MC} \cdot w_i^{Acc}$.

http://www-cdf.fnal.gov/ jsw/internal/GXG/PWA-corrections.md.html

Legendre moments - correction for acceptance

1. Statisical uncertainties:

$$cov(b_l, b_{l'}) = K^{-1}_{ll'} cov(a_l, a_{l'}) \left(K^{-1}_{ll'}\right)^T$$

We need the covariance of the mean value of the sample.

$$cov(a_l, a_{l'}) = \frac{\sum_{ij} w_i w_j cov(P_l(\cos\theta_i), P_{l'}(\cos\theta_j))}{\sum_{ij} w_i w_j}$$
$$= \frac{\sum_i w_i^2}{\sum_{ij} w_i w_j} cov(P_l(\cos\theta), P_{l'}(\cos\theta))$$

Let us denote: $V_1 = \sum_i w_i$, $V_2 = \sum_i w_i^2$, then:

$$cov(a_l, a_{l'}) = \frac{V_2}{V_1^2}\frac{V_1}{V_1^2 - V_2}\sum_i w_i(P_l(\cos\theta_i) - a_l)(P_{l'}(\cos\theta_i) - a_{l'})$$
$$= \frac{V_2}{V_1^2 - V_2}\left(\frac{\sum_i w_i P_l P_{l'}}{V_1} - a_l a_{l'}\right) = \frac{V_2}{V_1^2 - V_2}(\langle P_l P_{l'}\rangle - a_l a_{l'})$$

Legendre moments - correction for acceptance

2. Uncertainties linked with $\mathbf{K}^{-1}$ matrix: related to statistics of our MC sample

M. Lefebvre, R.K. Keeler, R. Sobie, J. White, Propagation of Errors for Matrix Inversion, [arXiv:hep-ex/9909031]

Let us denote: $\epsilon_{lm} = \langle P_l P_m \rangle$:

$$cov(\epsilon_{ab}^{-1}, \epsilon_{cd}^{-1}) = \sum_{ijkl} \epsilon_{ai}^{-1} \epsilon_{jb}^{-1} \epsilon_{ck}^{-1} \epsilon_{ld}^{-1} cov(\epsilon_{ij}, \epsilon_{kl}) \,,$$

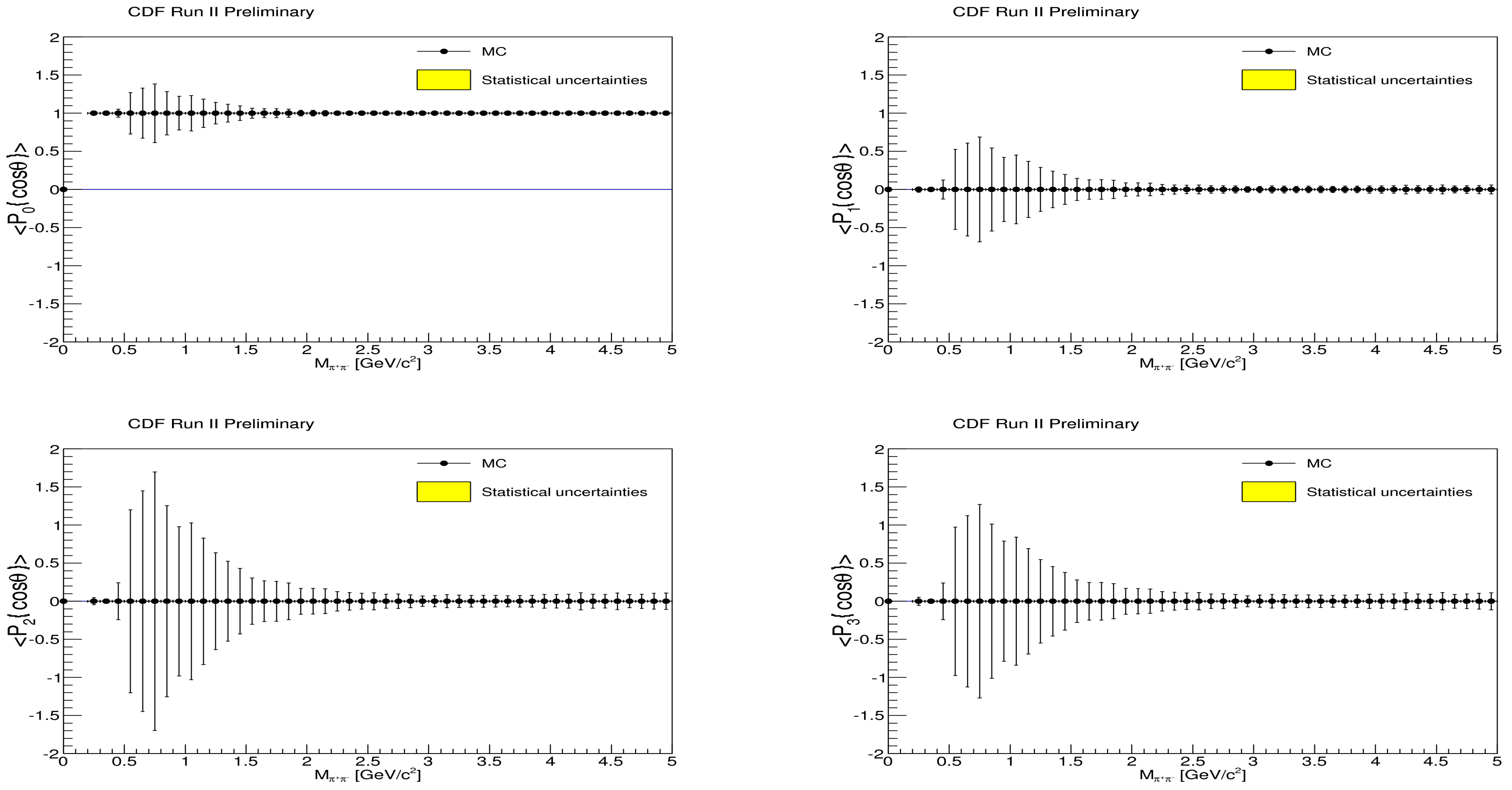
thus:

$$\delta b_i^2 = \sum_{jk} a_j cov(\epsilon_{ab}^{-1}, \epsilon_{cd}^{-1}) a_k$$

$cov(\epsilon_{ab}^{-1}, \epsilon_{cd}^{-1})$ - calculated in analogous way as in 1.

3. Systematical uncertainties: We varied all parameters (in Data and MC) and checked the result in Legendre moments plots.

MC – no weighting



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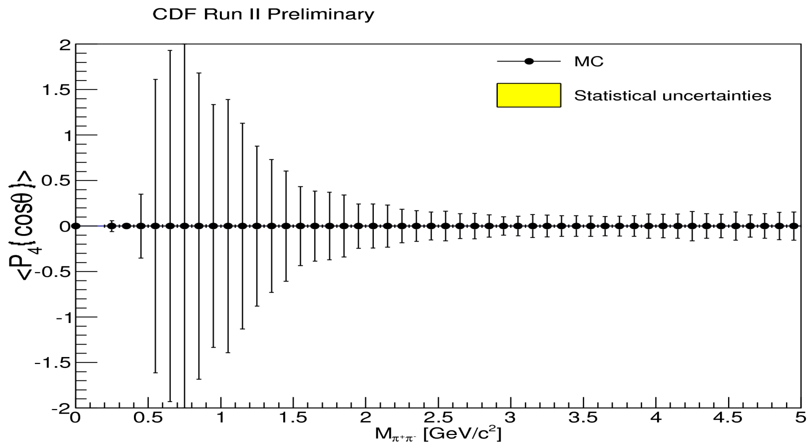

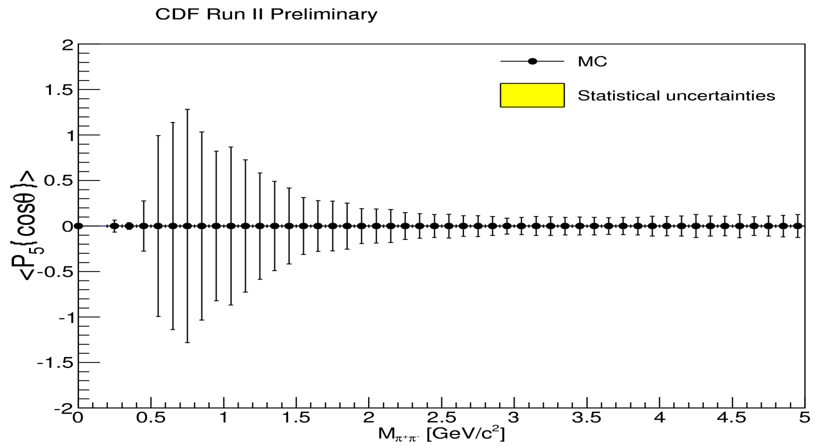

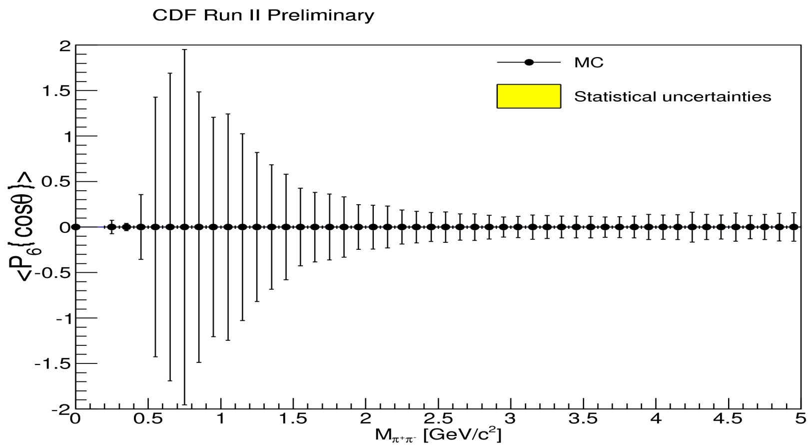

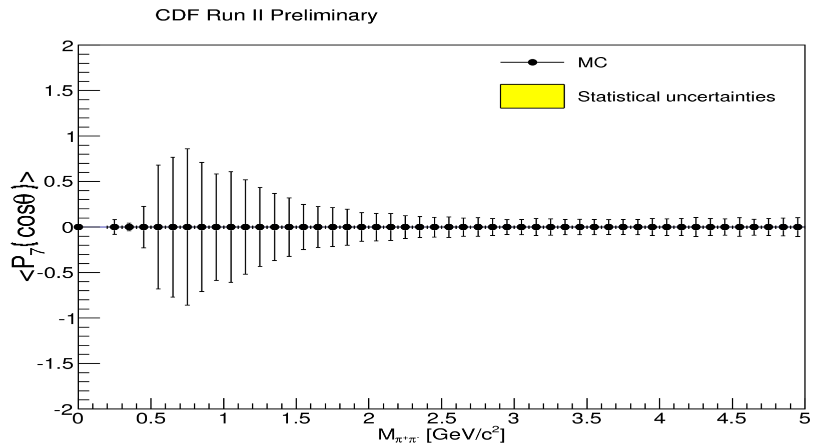

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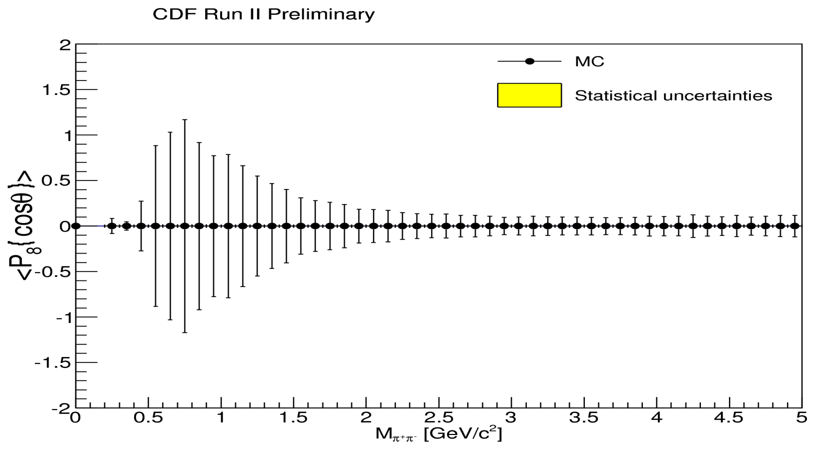
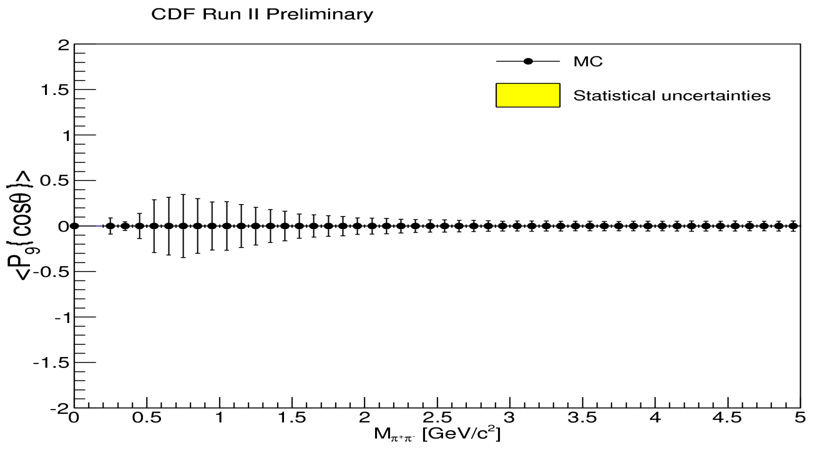
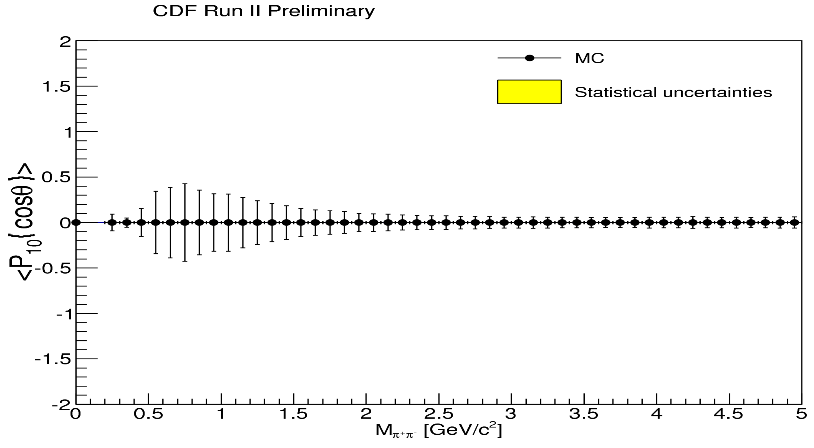
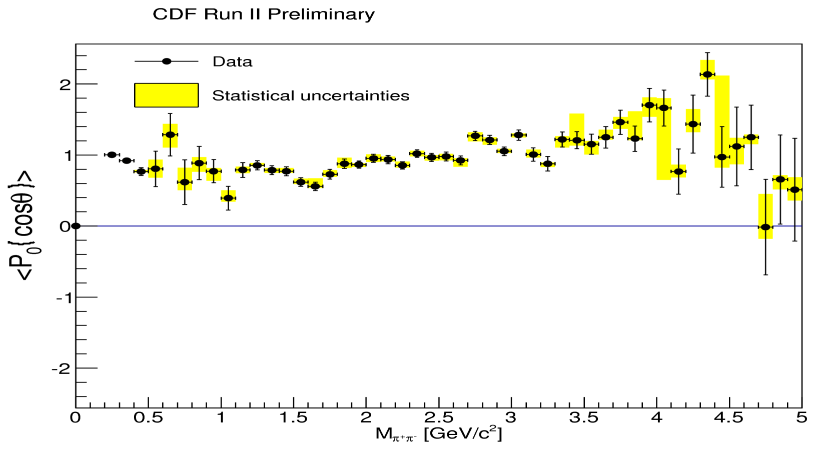
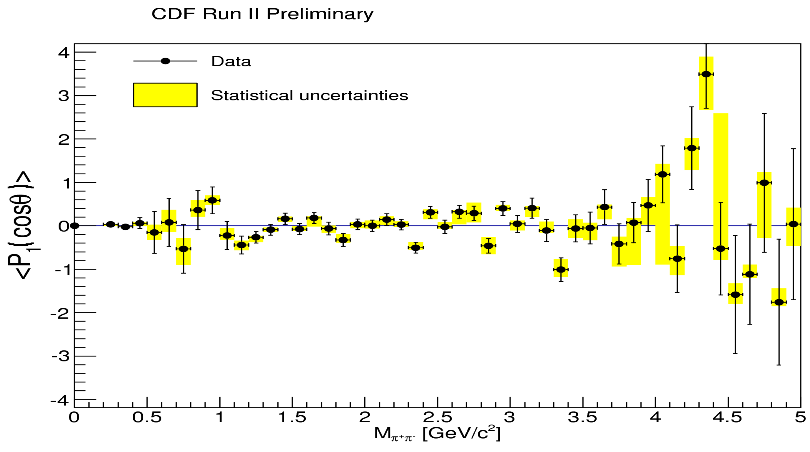


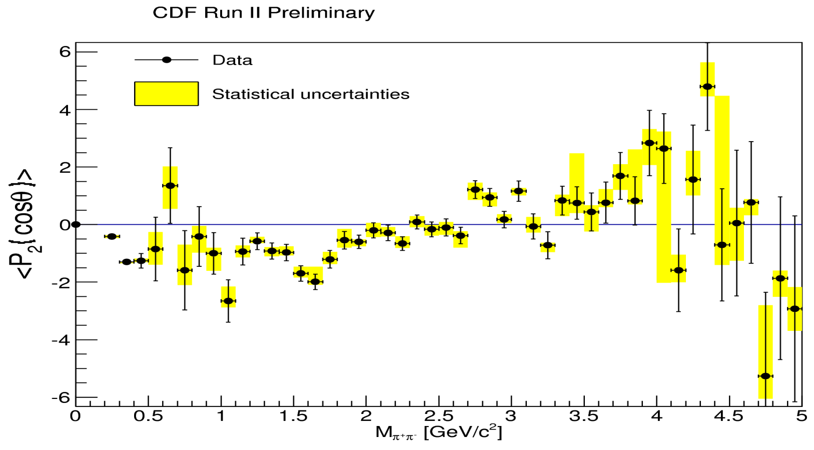


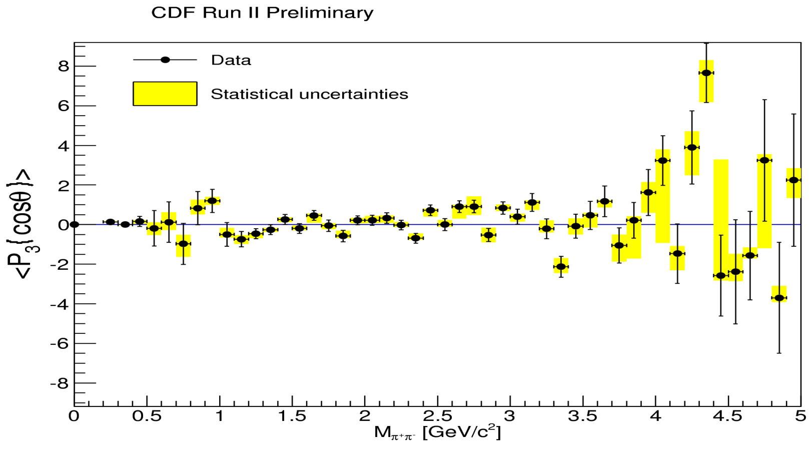


Data – no MC weighting









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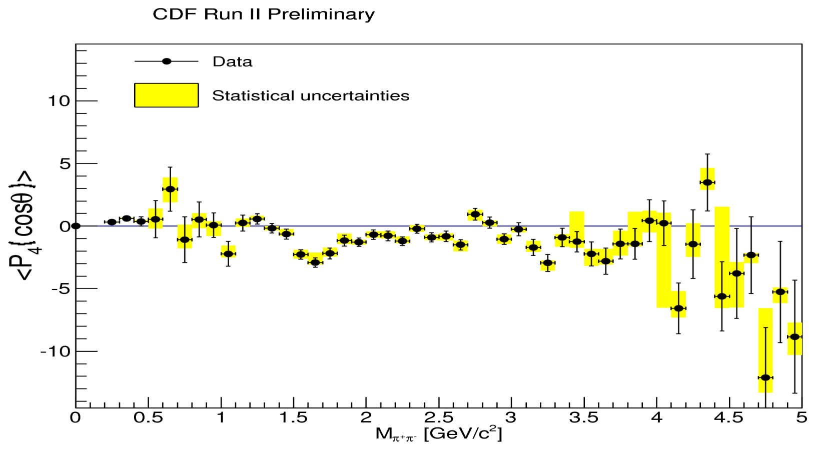

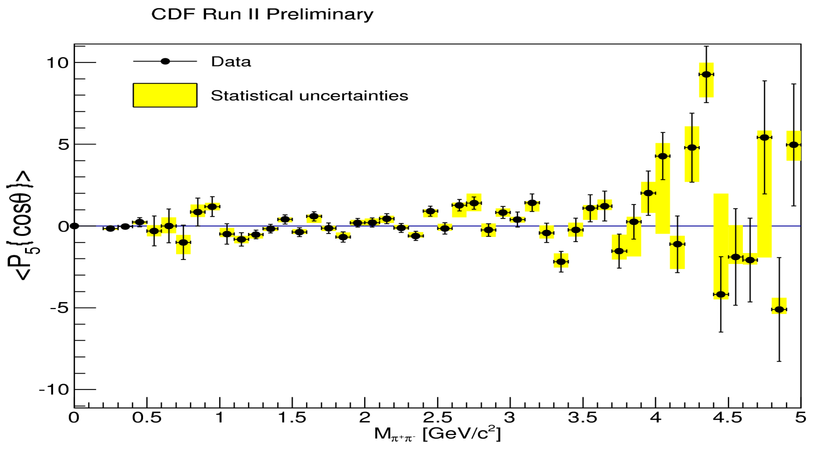

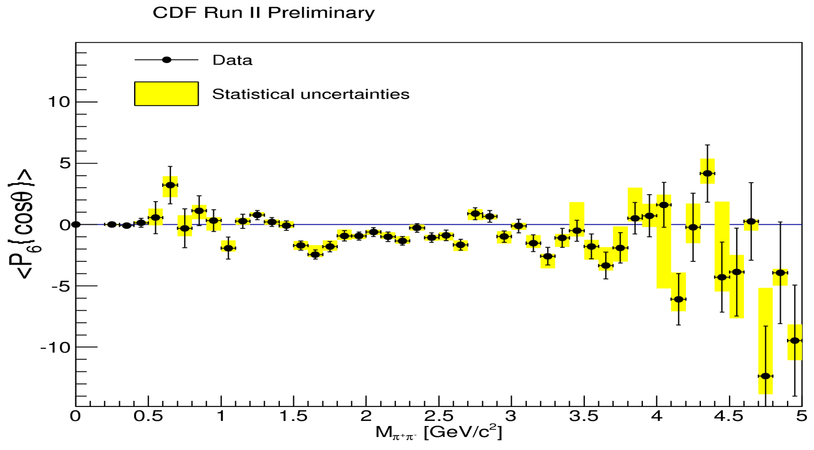

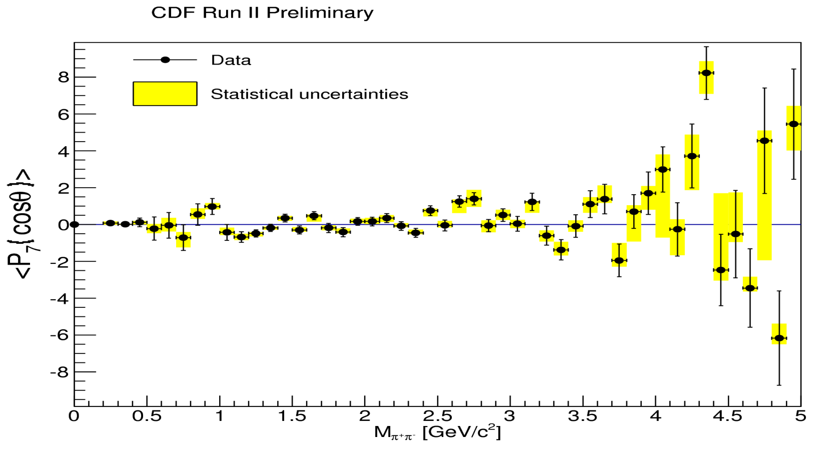

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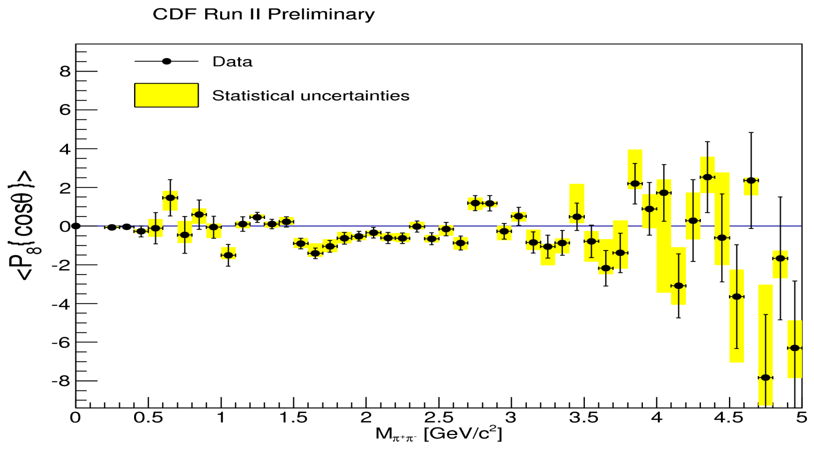
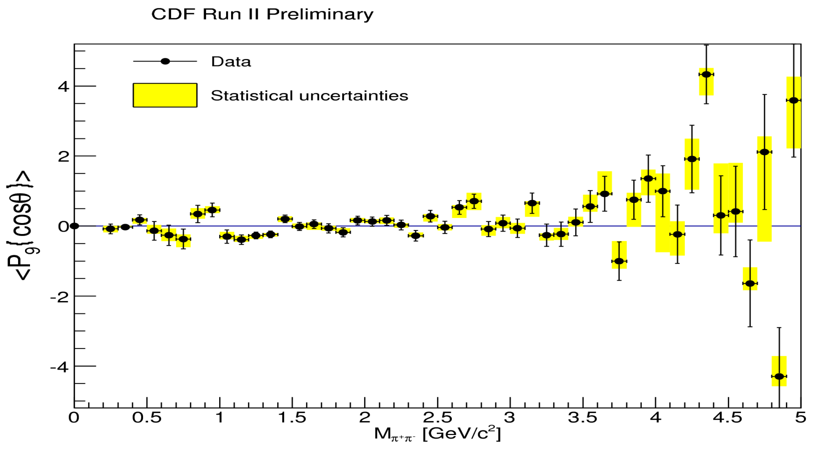
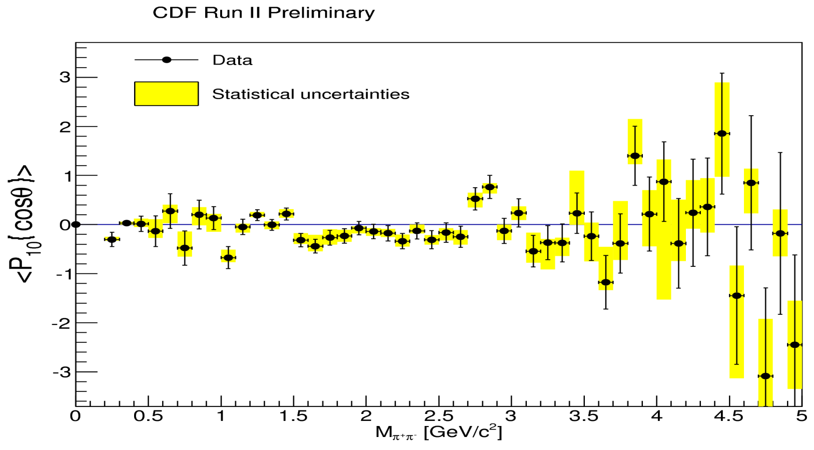
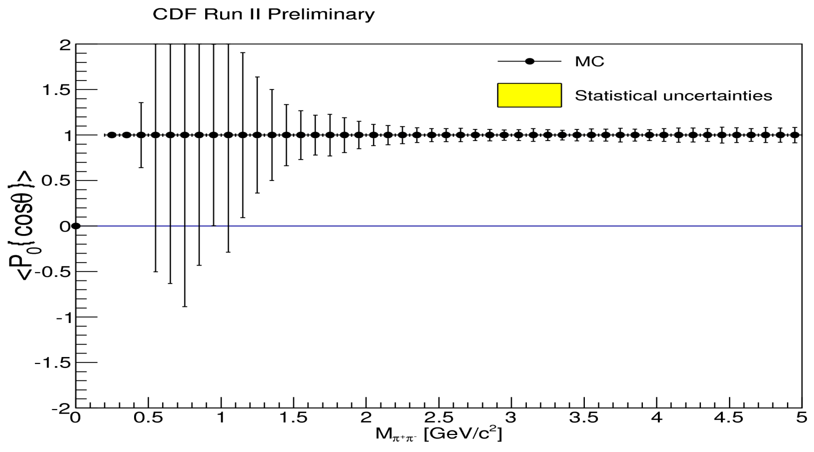
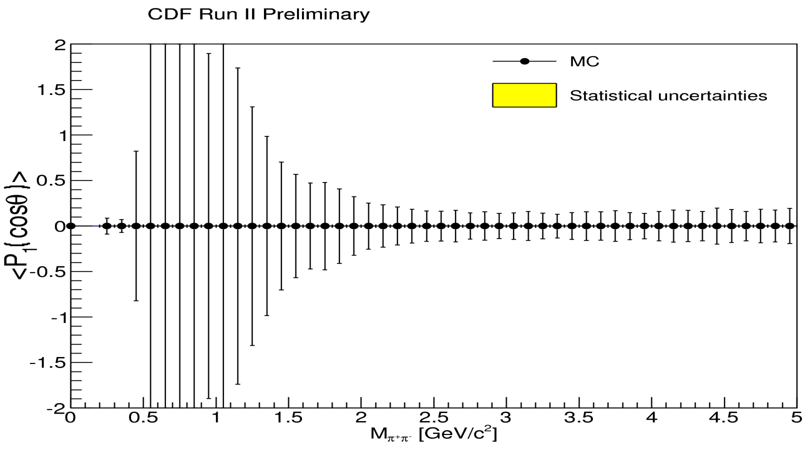


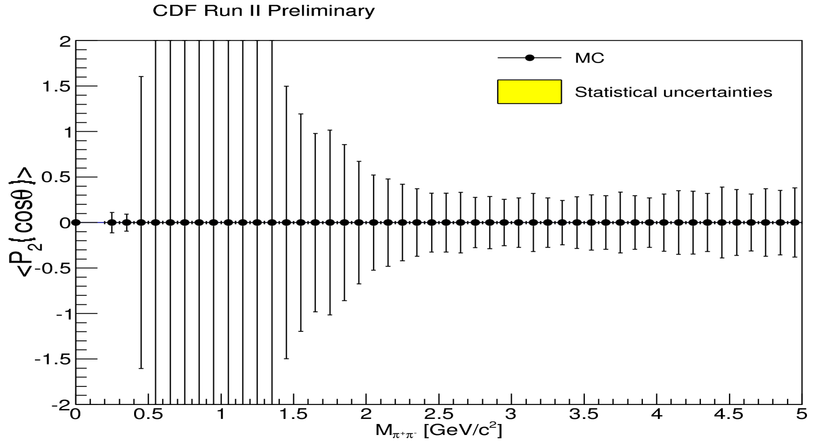


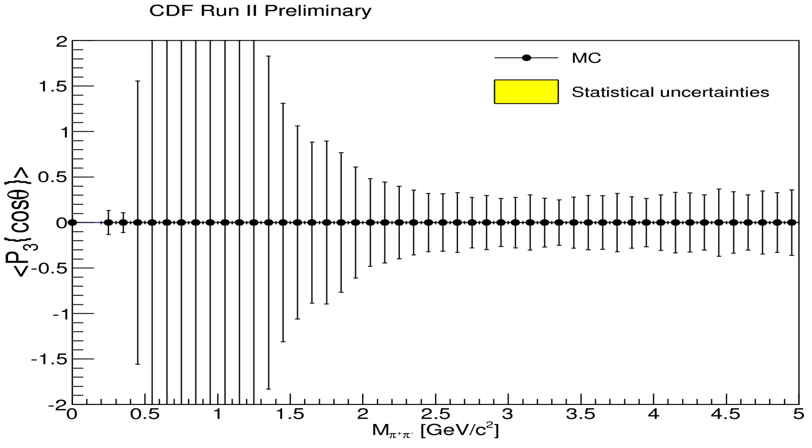


MC – weighting

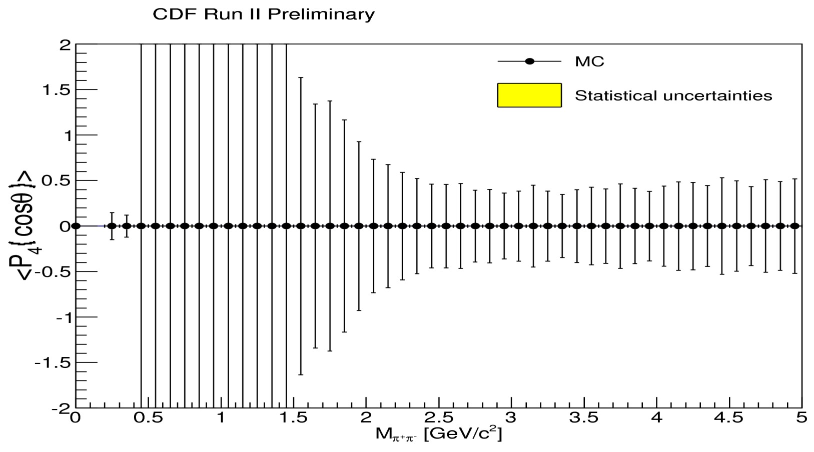


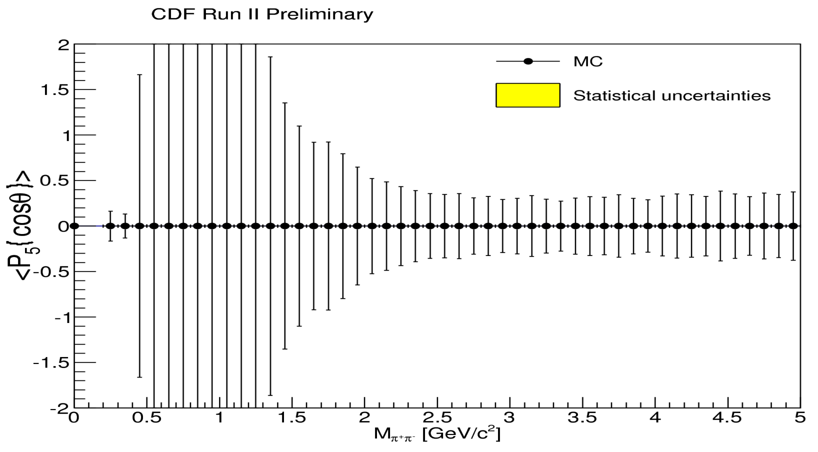


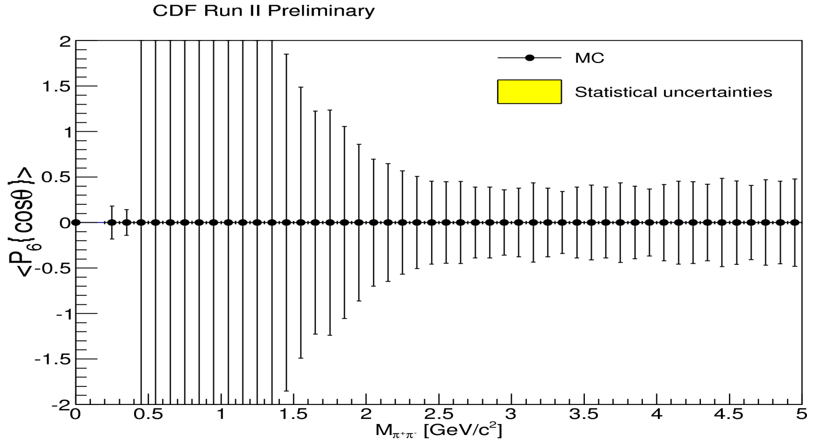


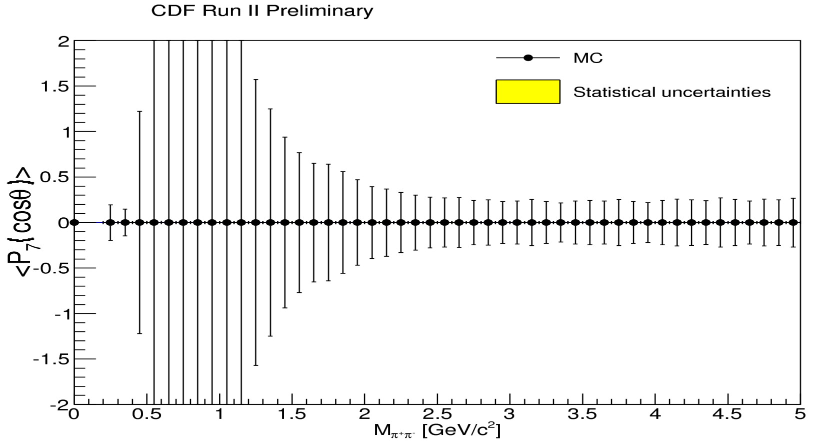


MC – weighting

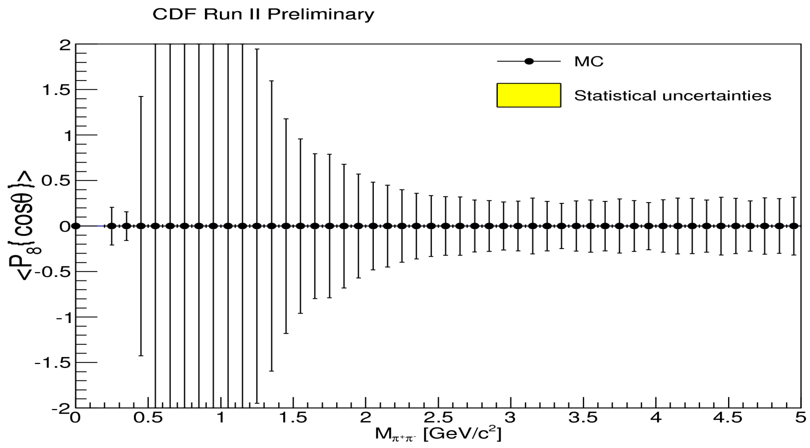


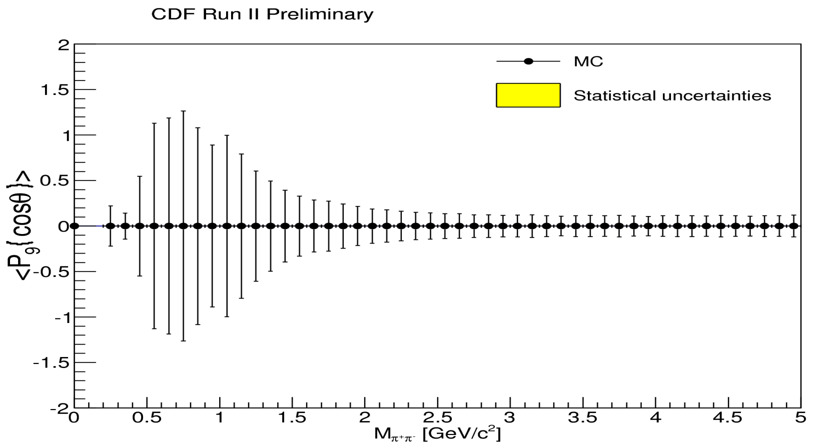


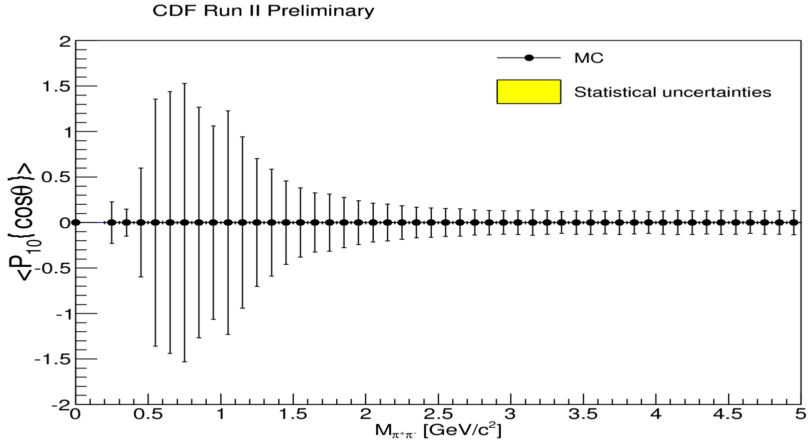




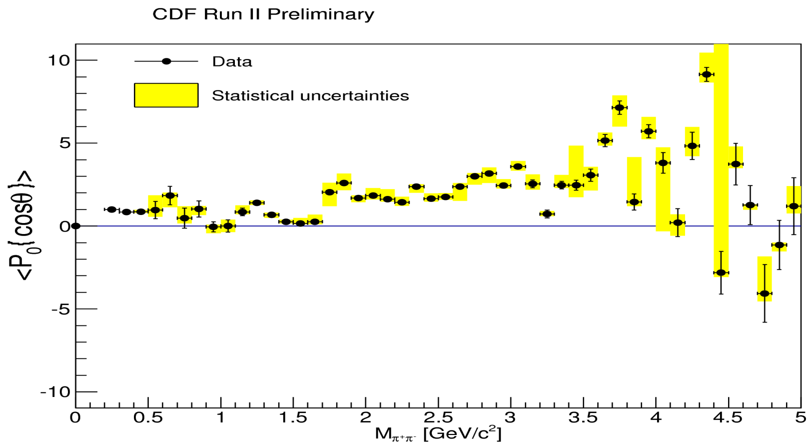
MC – weighting

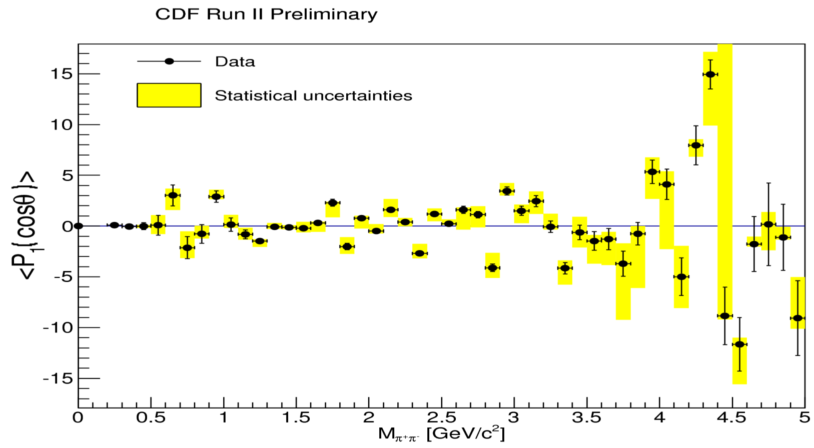


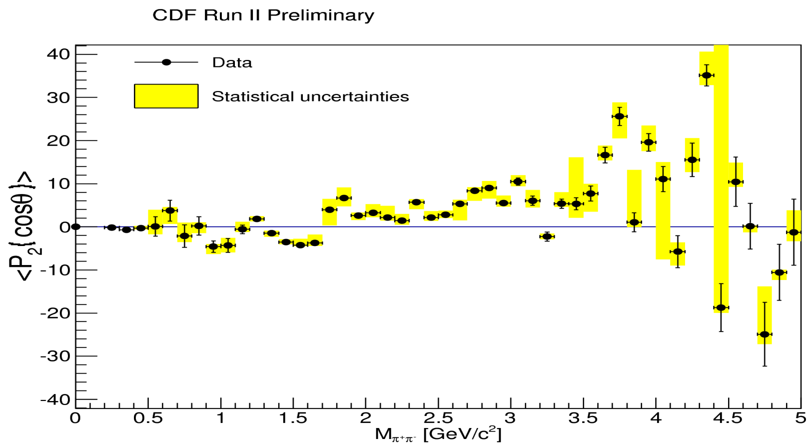


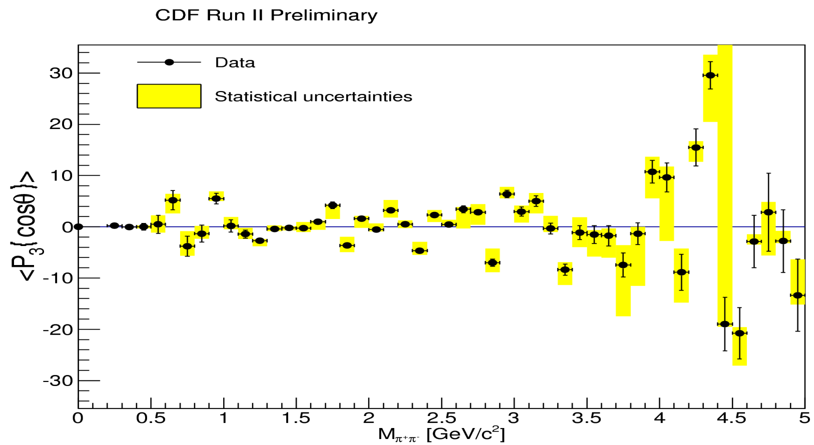


Data – MC weighting

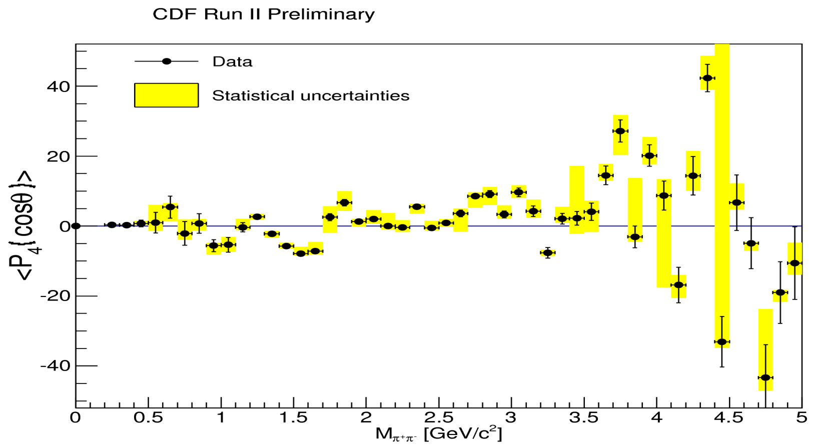


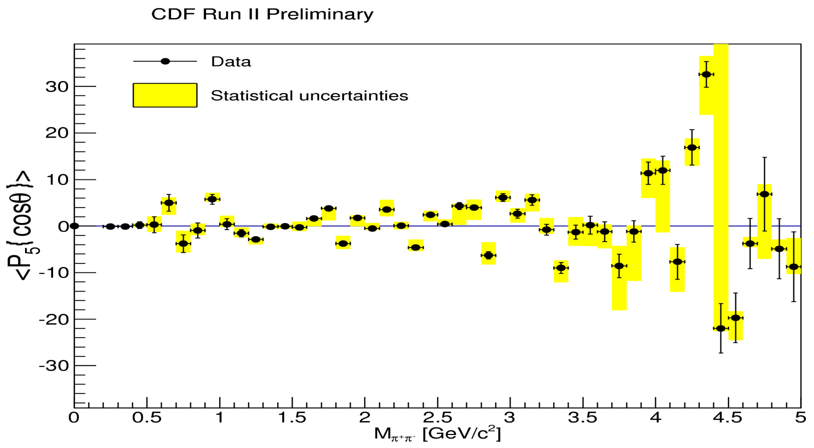


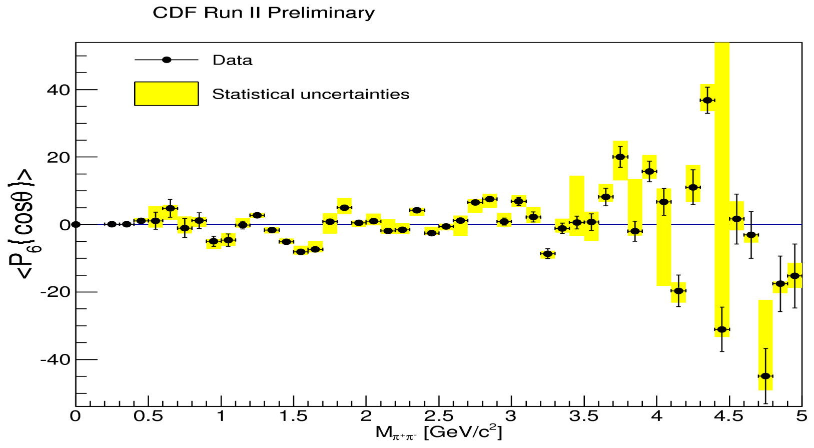


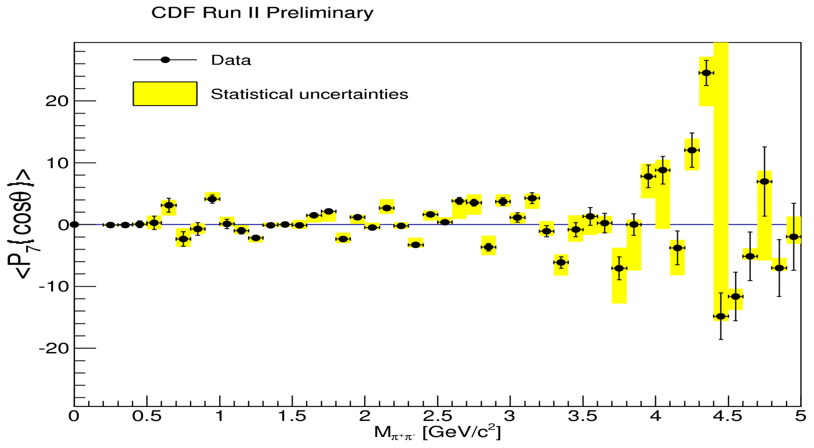


Data – MC weighting

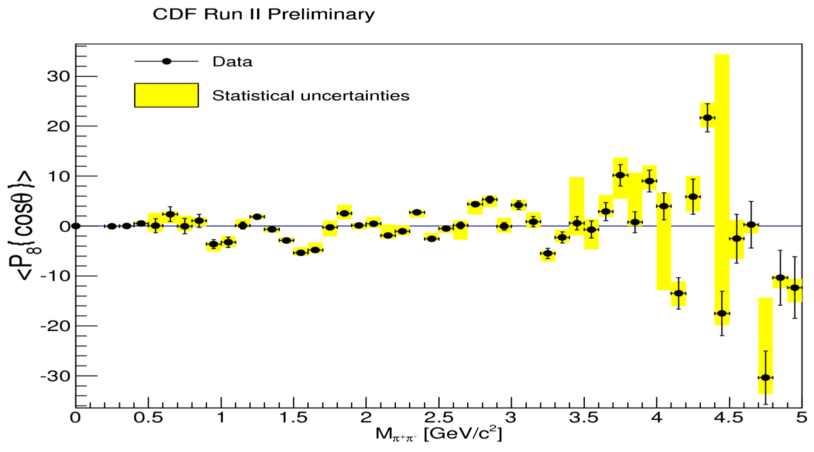


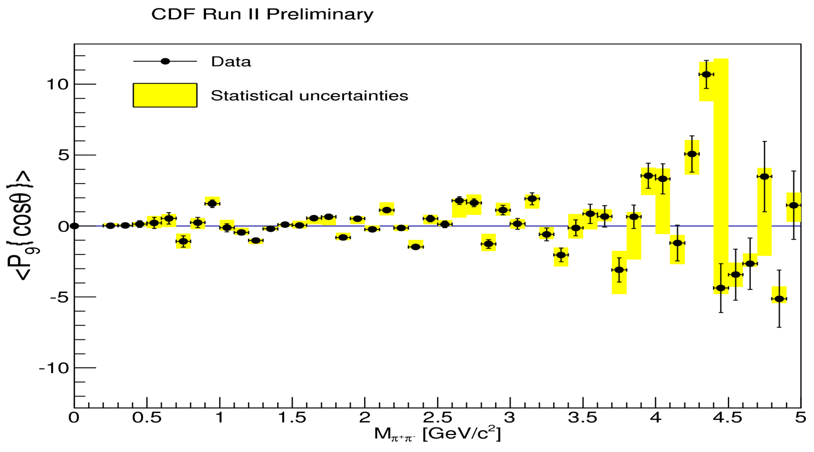


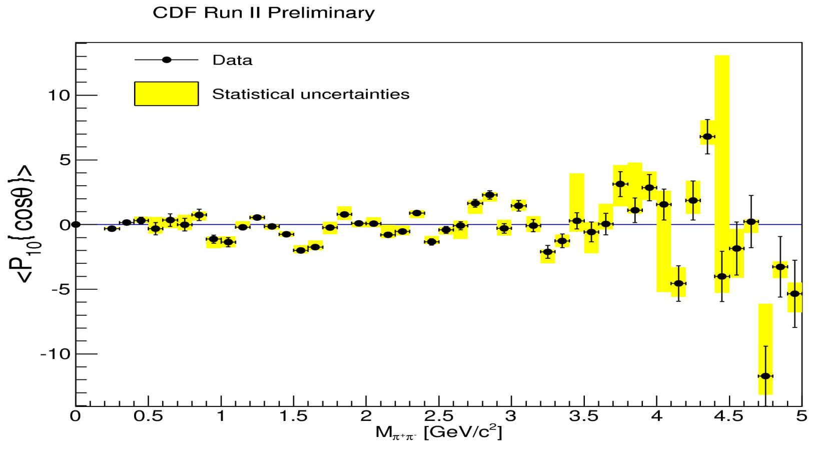




Data – MC weighting







Conclusions

- **We have measured $\pi^+\pi^-$ pairs between large rapidity gaps at the Tevatron, which should be dominated by double pomeron exchange.**
  The background from K^+K^- is small.
- **We do not see a ρ(770), confirming that photoproduction and ρ-exchange, are negligible.**
- **This is the only measurement from the Tevatron, and has much higher statistics than preliminary data from the LHC experiments.**
- **The mass spectra show several structures:**
  - Broad continuum below 1 GeV/c^2,
  - Sharp drop at 1 GeV/c^2
  - Resonant enhancement around 1.0 – 1.5 GeV/c^2.
- **The s-dependence is mass dependent.**
- **We plan to do a partial wave analysis to distinguish different spin states.**

Thank you

Backup slides

Data sample

- Datasets used:
  - gdifap – 1960 GeV
  - gdifar – 900/300 GeV
- Same trigger requirement: DIFF_TWO_CJET0.5_PLUGVETO_0.75
  - 2 central ($|\eta|<1.32$) towers with Et > 0.5 GeV
  - Plug ($2.11<|\eta|<3.64$) in veto (Et <0.75 GeV)
  - BSC1 and CLC in veto
- L=7.12/pb – 1960 GeV and L=0.074/pb – 900 GeV
- Gaps at least from $|\eta|=1.3$ to $|\eta|=5.9$

Effective exclusive luminosity

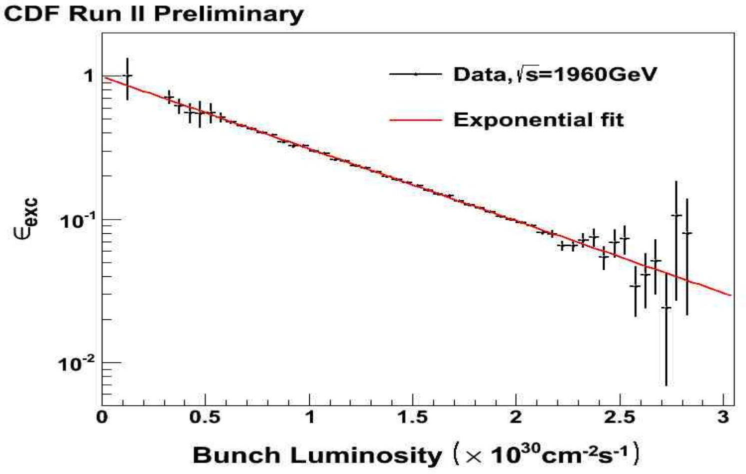
Efficiency of having no-pileup using zero-bias sample. We measure ratio of empty events (all detectors on noise level) to all events.

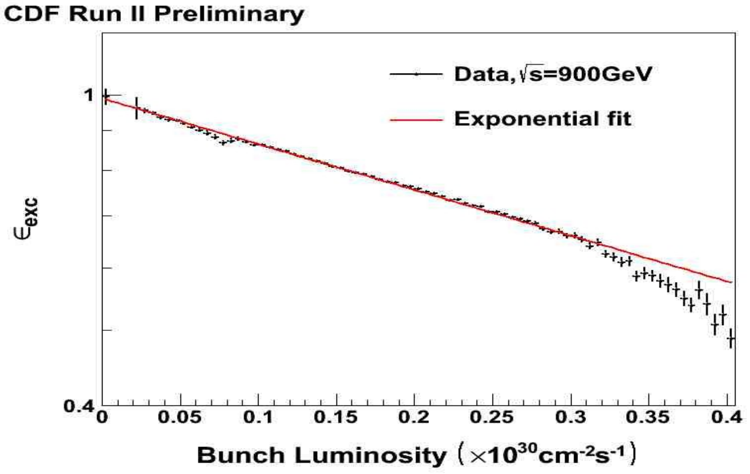
Should drop exponentially with bunch luminosity and be equal 1 at L=0

Slope corresponds to part of inelastic cross section with particles in |eta| < 5.9. (More low mass diffraction is included at 900 GeV than at 1960 GeV.):

- 53.88(36) mb – 1960 GeV
- 62.76(38) mb – 900 GeV

- Effective luminosities:
  - 1.18/pb – 1960 GeV
  - 0.059/pb – 900 GeV





Systematics - summary

Cut	**1960 GeV**	**900 GeV**
Exclusivity cut in CD	15%	15%
Forward Plug	6%	6%
Pt	2%	2%
Z0	2%	4%
BSC	2%	4%
Luminosity	6%	6%
χ^2	3%	3%
Total:	20%	20%